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TOPOLOGICAL TRANSITIONS IN A SUPERCONDUCTING QUBIT

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INTRODUCTION

Superconducting Josephson Junction resonators are highly tunable quantum systems. There is a field developing around the topology of quantum systems and recently, methods have been uncovered to measure a topological transition of the first Chern number (C_1). The following experimental setup is a great place to learn more about these topological effects.

SUPERCONDUCTING QUBITS

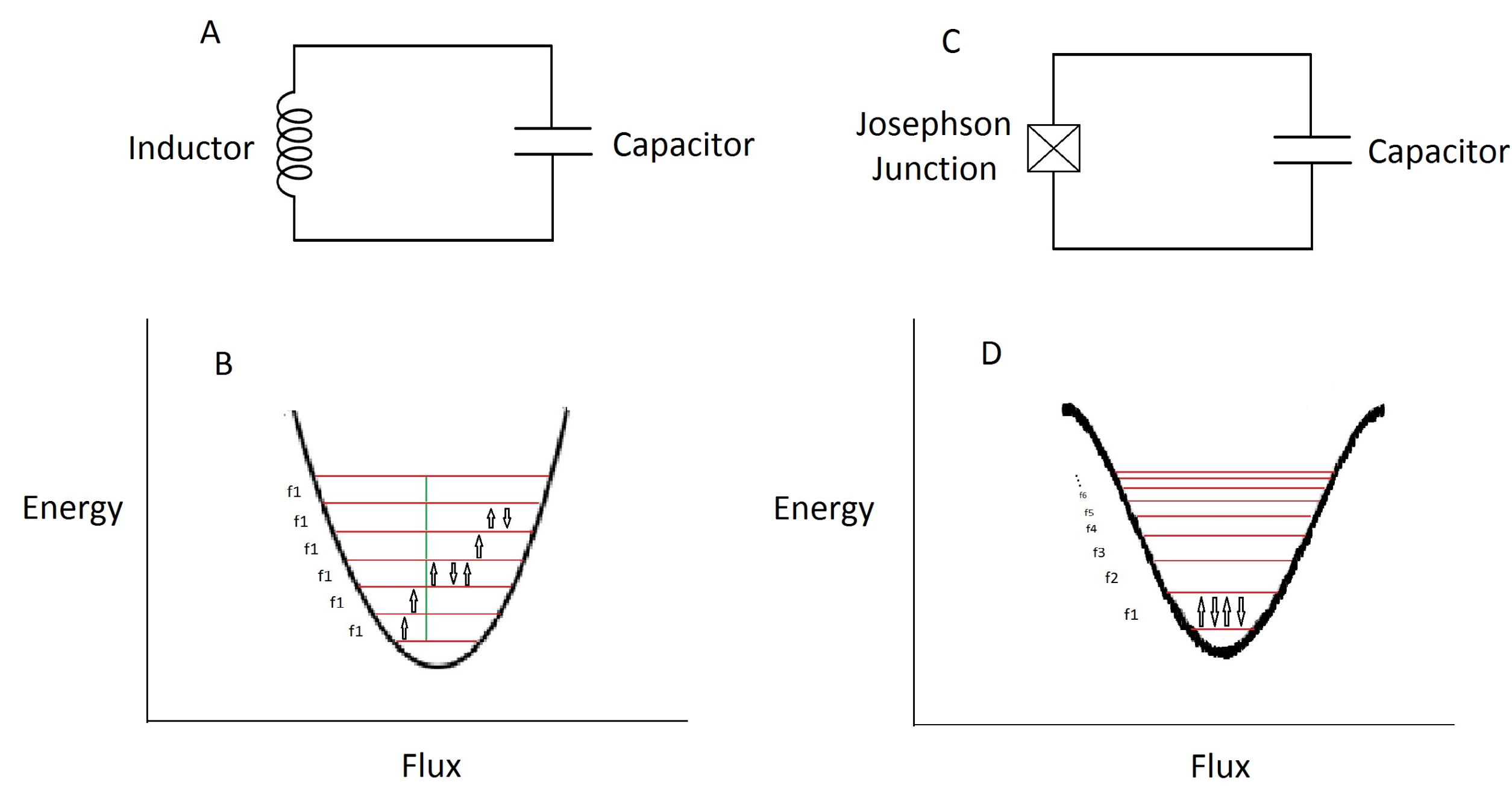


Figure 1: On the left we have an LC circuit which, at the correct resonance frequency, behaves as a harmonic oscillator with equally spaced energy levels. On the right, a Superconducting Josephson Junction shunted to a capacitor which acts as a nonlinear resonator.

We get a Hamiltonian in this system

$$H_q = \frac{\hbar}{2}(\delta\sigma_z + \Omega\sigma_x \cos \phi + \Omega\sigma_y \sin \phi) \quad (1)$$

With detuning δ , drive strength Ω , and Pauli matrices σ_z , σ_x , and σ_y .

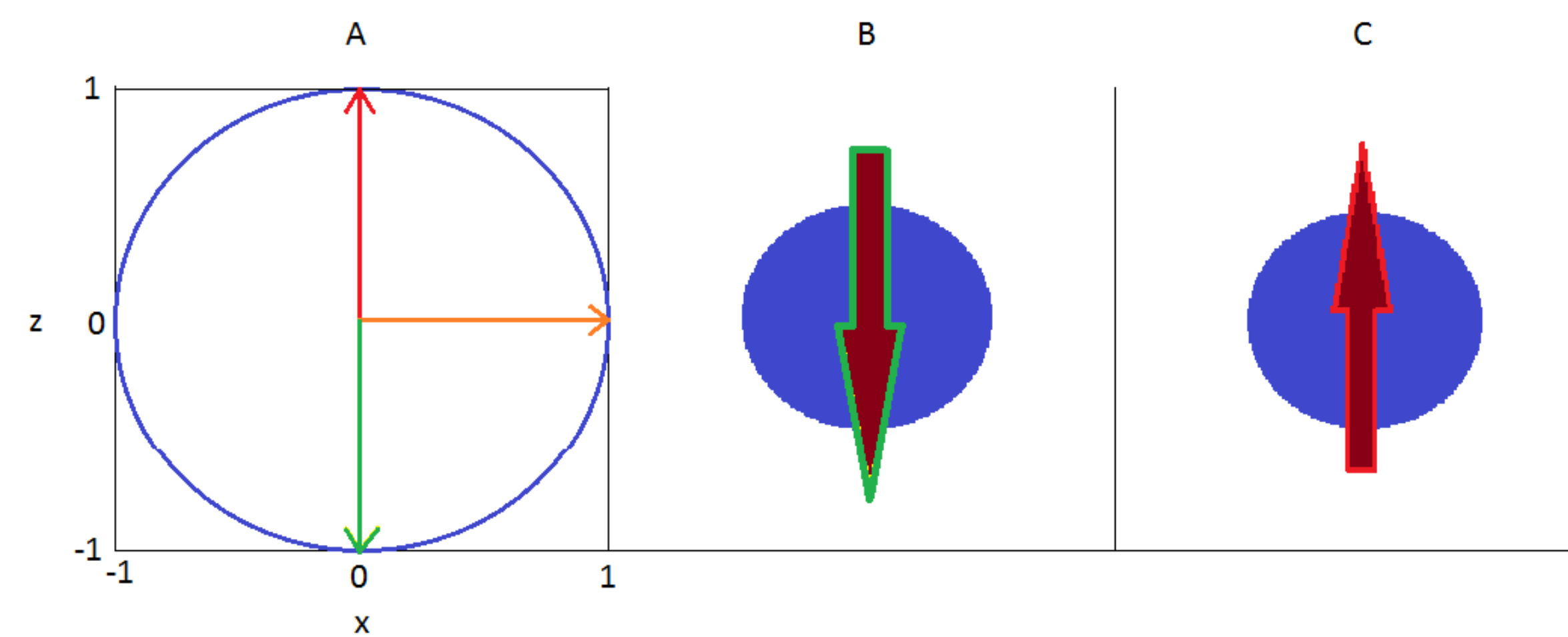


Figure 2: Any qubit state can be represented by a point inside of a sphere called the Bloch sphere. In part (A) we have the (x,z) projection of the Bloch sphere. The green line is the ground state, the red line is the excited state, and the orange is a certain superposition of the two. This is analogous to the spins of the electrons shown in (B) and (C).

TOPOLOGY

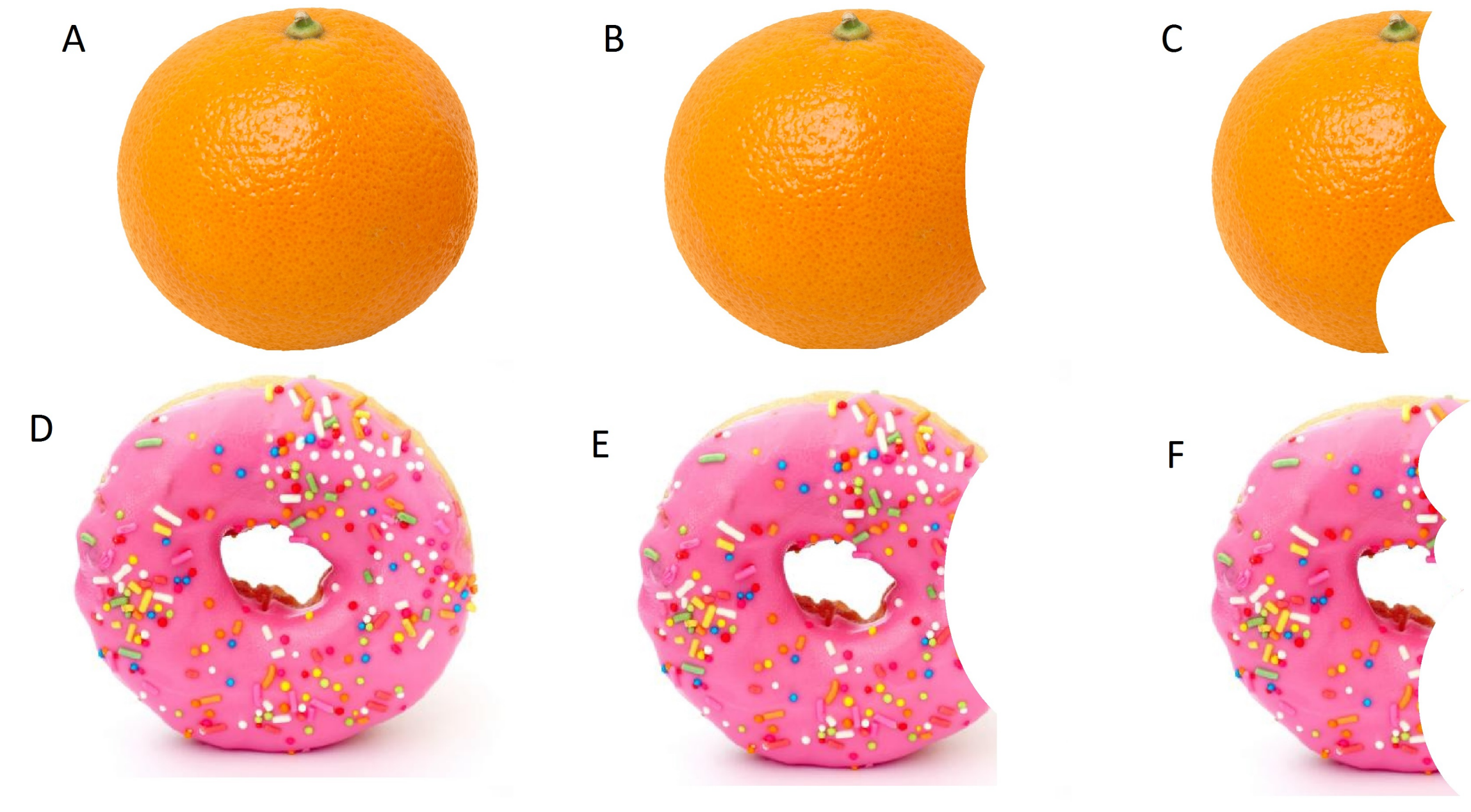


Figure 3: An orange and a donut are topologically different because a donut has a hole in it an orange does not. As we move to the second column and take a bite, this topological difference remains, but when we reach the third column, the two pieces of food are no longer topologically different. This is a topological transition.

Topology is the study of how some aspects of a system remain the same under changing parameters. The first Chern number is a topological invariant which counts the number of degeneracies inside of a closed manifold in Hilbert space. It is equal to the integral of the Berry Curvature over a closed loop

$$C_1 = \frac{1}{2\pi} \oint_s F \cdot dS \quad (2)$$

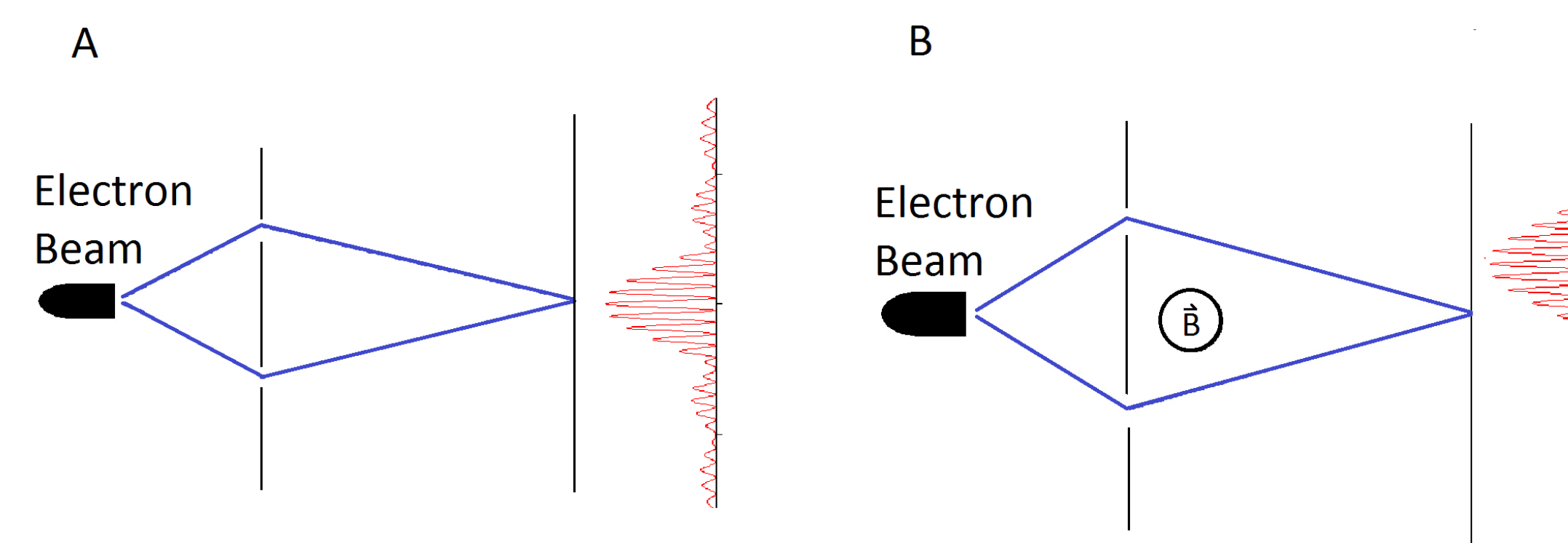


Figure 4: The Aharnov-Bohm effect involves the same physics as the calculation of the Chern number. As the electrons move around the degeneracy, in this case a localized magnetic field, they gain phases which shift the ubiquitous Young-Fraunhofer interference pattern.

CONTACT INFORMATION

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REFERENCES

M. D. Schroer, et. al., Phys. Rev. Lett., 113(050402), August 2014.

RESULTS

There is a degeneracy at $\Omega = \delta = 0$. For our experiment,

$$C_1 = \int_0^\pi F_{\theta\phi} d\theta \quad (3)$$

$$F_{\theta\phi} = \frac{\Omega_1 \sin(\theta)}{2v_\theta} \langle \sigma^y \rangle \quad (4)$$

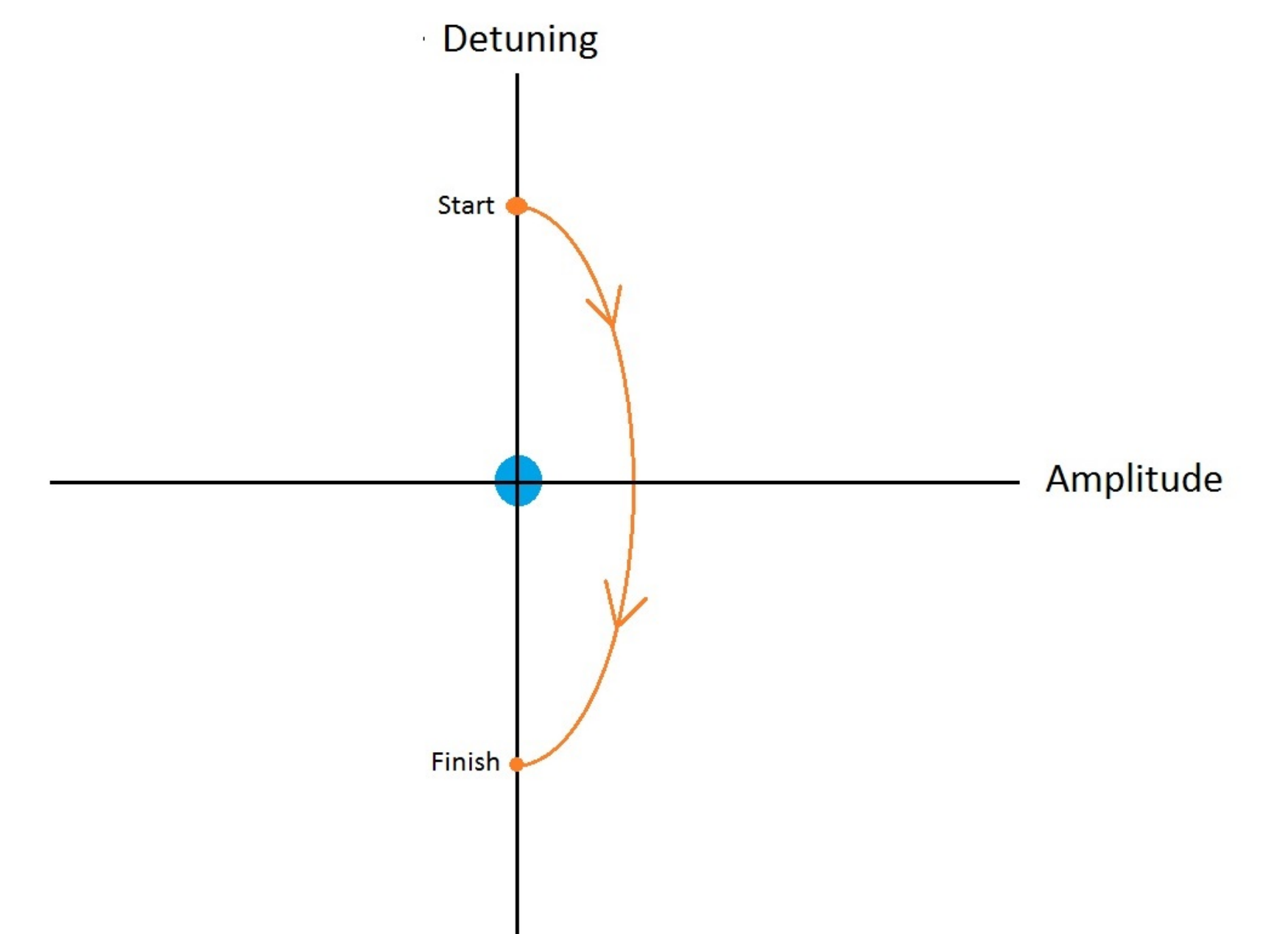


Figure 5: The experimental drive as a function of Amplitude and Detuning, with a degeneracy shown at the center

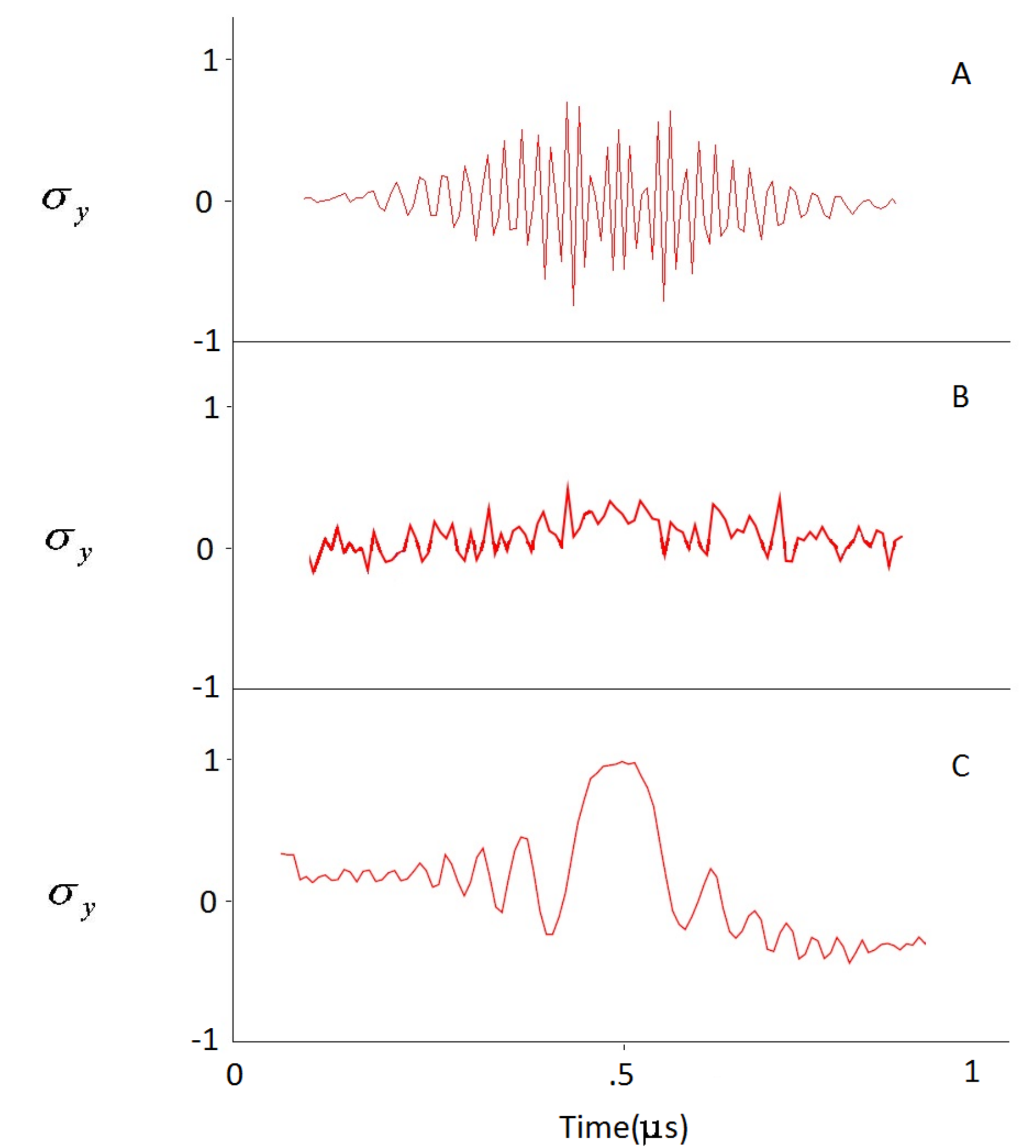


Figure 6: Some problems arose having to do with inconsistent rotation of the qubit state resulting from the varying drive detuning. (A) is raw data from a standard measurement procedure. (B) is data manipulated to counteract the qubit rotation. (C) is raw data from a procedure where the measurement was rotated at the same rate as the qubit. Further analysis is needed to show if the rotation methods used for B and C worked.